Rapidly Deployable Wireless Networks for Emergency Communications & Sensing Applications
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INTRODUCTION

Rapidly Deployable Networks: Rationale

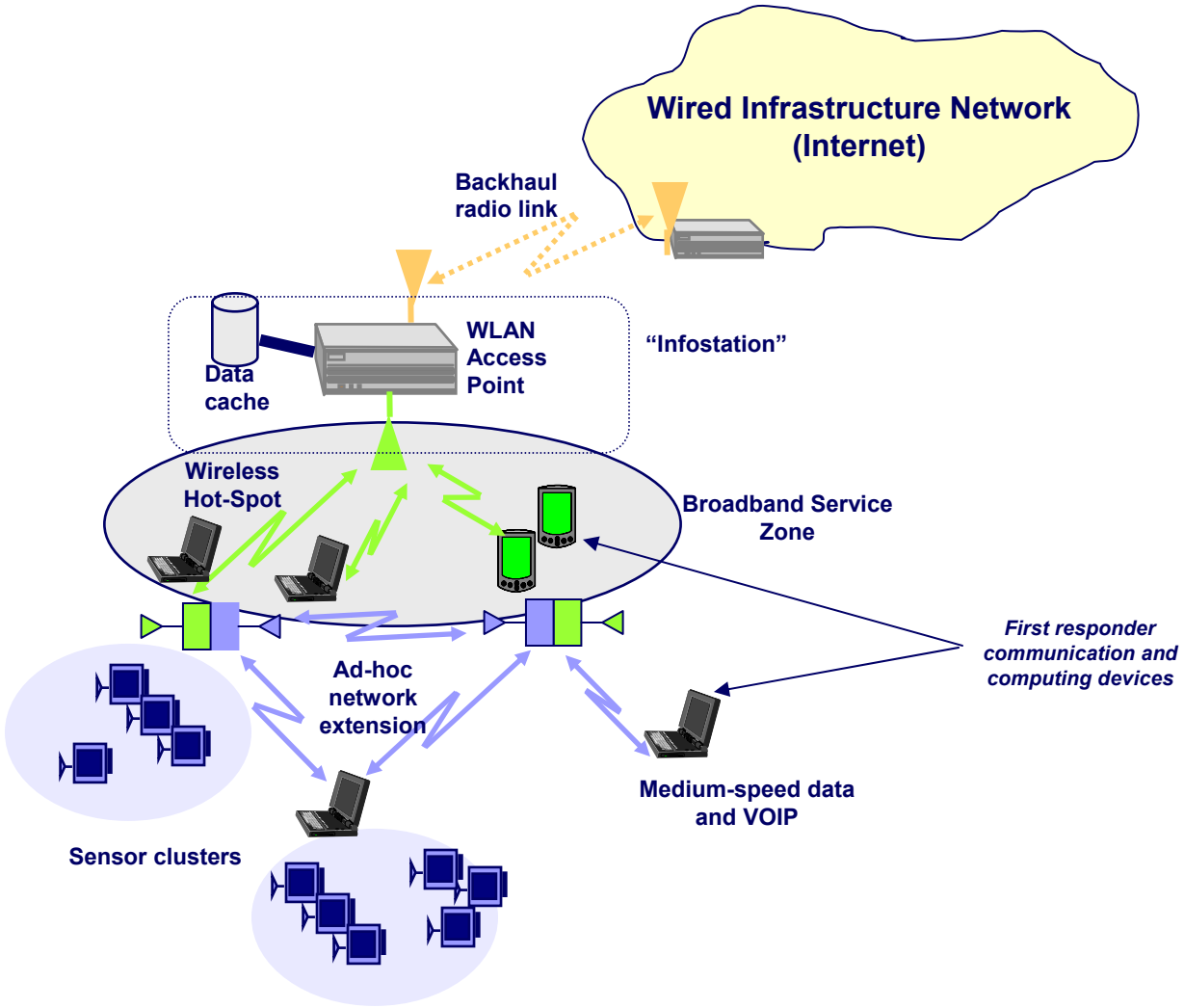
- Failure of communication networks is a critical problem faced by first responders at a disaster site
  - major switches and routers serving the region often damaged
  - cellular cell towers may survive, but suffer from traffic overload and dependence on (damaged) wired infrastructure for backhaul
- In addition, existing networks even if they survive may not be optimized for services needed at site
  - significant increase in mobile phone traffic needs to be served
  - first responders need access to data services (email, www,...)
  - new requirements for peer-to-peer communication, sensor net or robotic control at the site
- Motivates need for rapidly deployable networks that meet both the above needs -> recent advances in wireless technology can be harnessed to provide significant new capabilities to first responders....

Rapidly Deployable Networks: Wireless Technology

- Several wireless technology options have been available for the last ~10-20 yrs
  - mini cell stations using existing standards like CDMA or GSM
  - wireless PABX using PCS standards such as DECT or PHS/PACS
  - satellite and microwave backhaul
- Above solutions OK for voice & low-speed data, but do not meet emerging needs for broadband access and mobile data
- Emerging mainstream wireless technologies provide powerful building blocks for next-generation emergency response nets
  - WLAN (IEEE 802.11 “WiFi”) hot-spots for broadband access
  - Context-aware mobile data services and web caching for information services
  - Wireless sensor nets for monitoring and control
  - VOIP for integrated voice services over wireless data networks

Rapidly Deployable Wireless Network:

Proposed Architecture



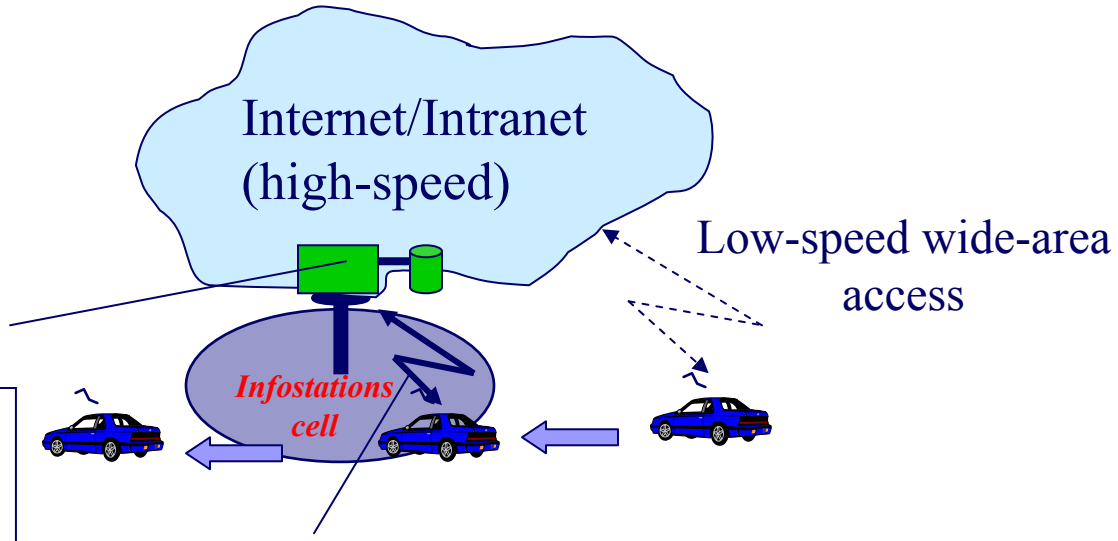
Rapidly Deployable Networks: WINLAB Research Projects

- WINLAB has several projects on emerging wireless technologies directly applicable to rapid deployment....
- Infostations
  - "hot-spot" for facilitating complex information retrieval by first responders
  - may also be used for standard WLAN services in limited area
- Ad-hoc WLAN
  - Ad-hoc extensions to WLAN hot-spot service via multi-hop routing
  - WLAN data services (and VOIP) with increased coverage
- Sensor networks
  - Ad-hoc networks of radio sensors that integrate well with WLAN hot-spots as the "infrastructure"
  - Specialized services and applications with quality-of-service & energy constraints
- VOIP over wireless
  - Transport and control protocols for voice services over packet data networks, including specializations for wireless impairments
- Spectrum etiquette
  - Coordination techniques for easing "traffic jams" in dense wireless deployments

Infostations

Infostations: Service Concept

- Using radio hot-spots (WLAN, other...) to deliver context- and location-aware information to mobile users
  - adaptive operations include: detection of Infostation, adaptive bit-rate selection, dynamic association and opportunistic data delivery

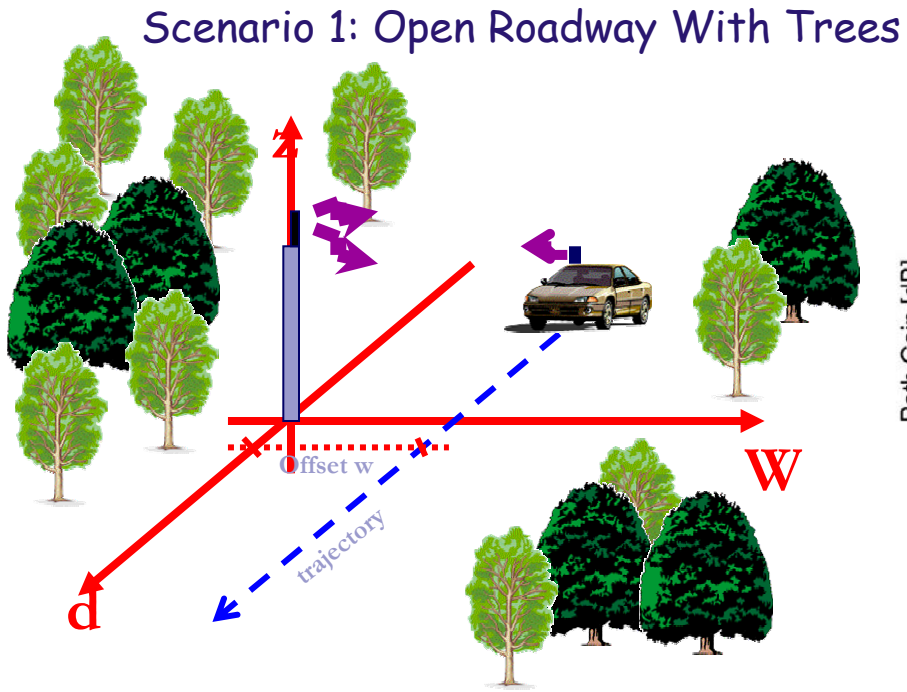


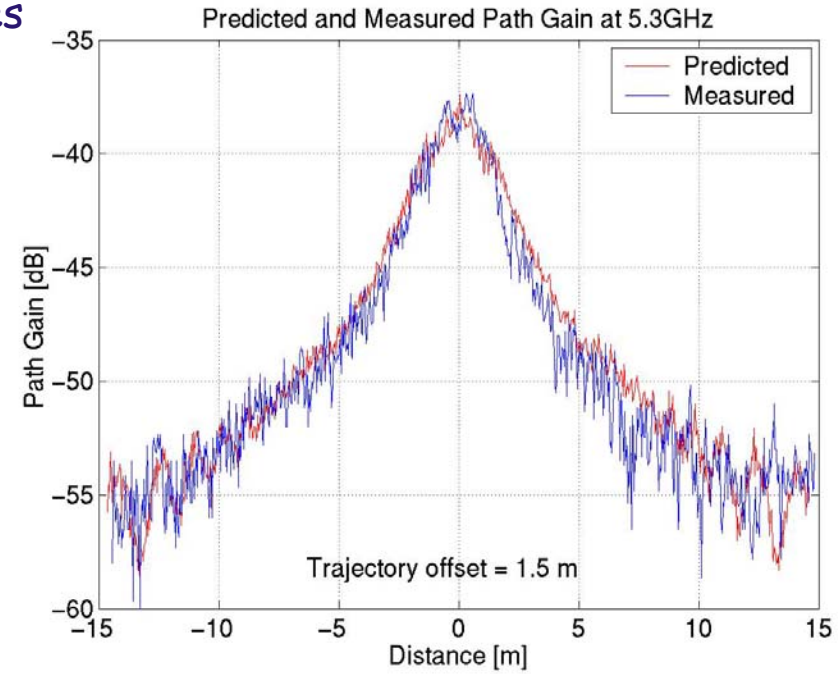
Key technologies:
- *Super high-speed short range modem*
- *MAC optimized for file transfer*
- *opportunistic file delivery protocol*

Infostations:
Short-Range Radio Propagation

Results show that channel is well-behaved for distance ~5-10m → 100's of Mbps achievable with OFDM, UWB or other modulations

(...802.11a adapting to max 54 Mbps can be used as a first approximation)

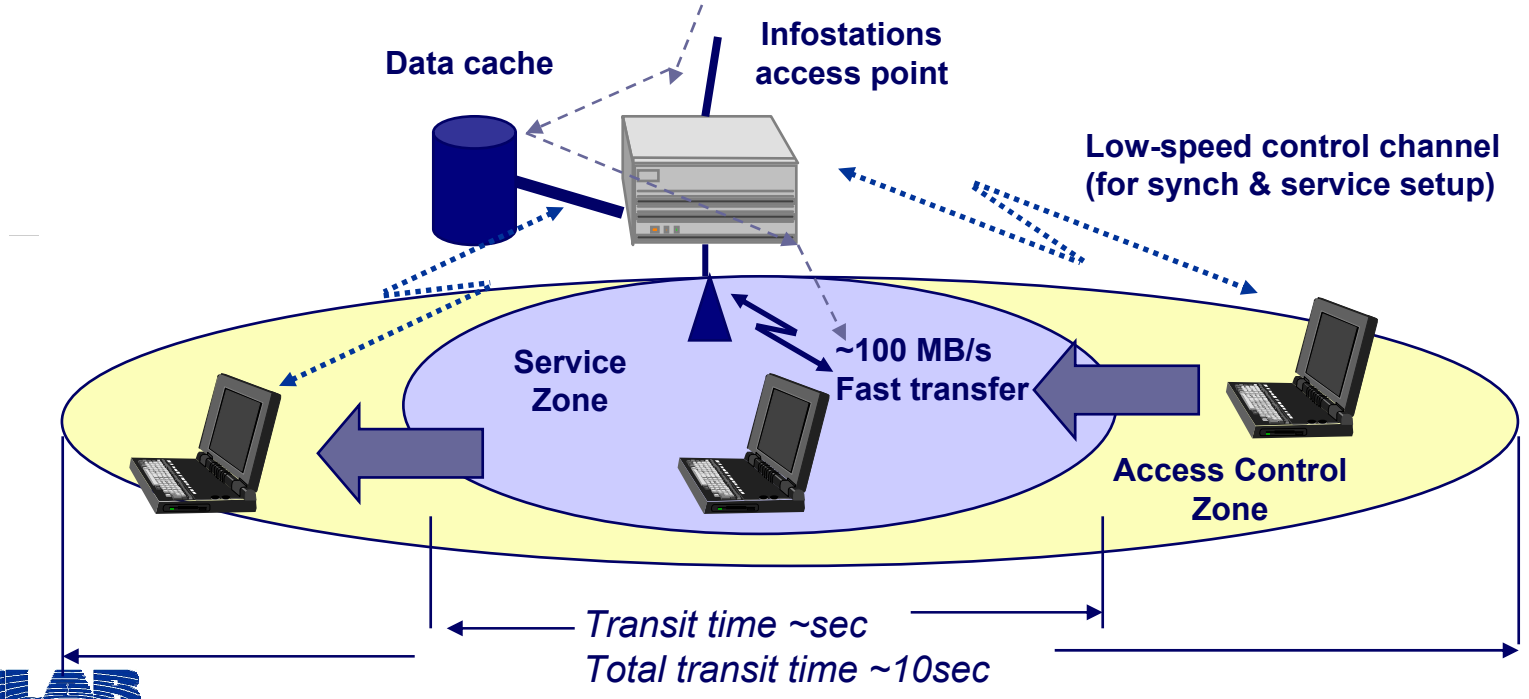




Measured data from Domazetovic & Greenstein [2001]

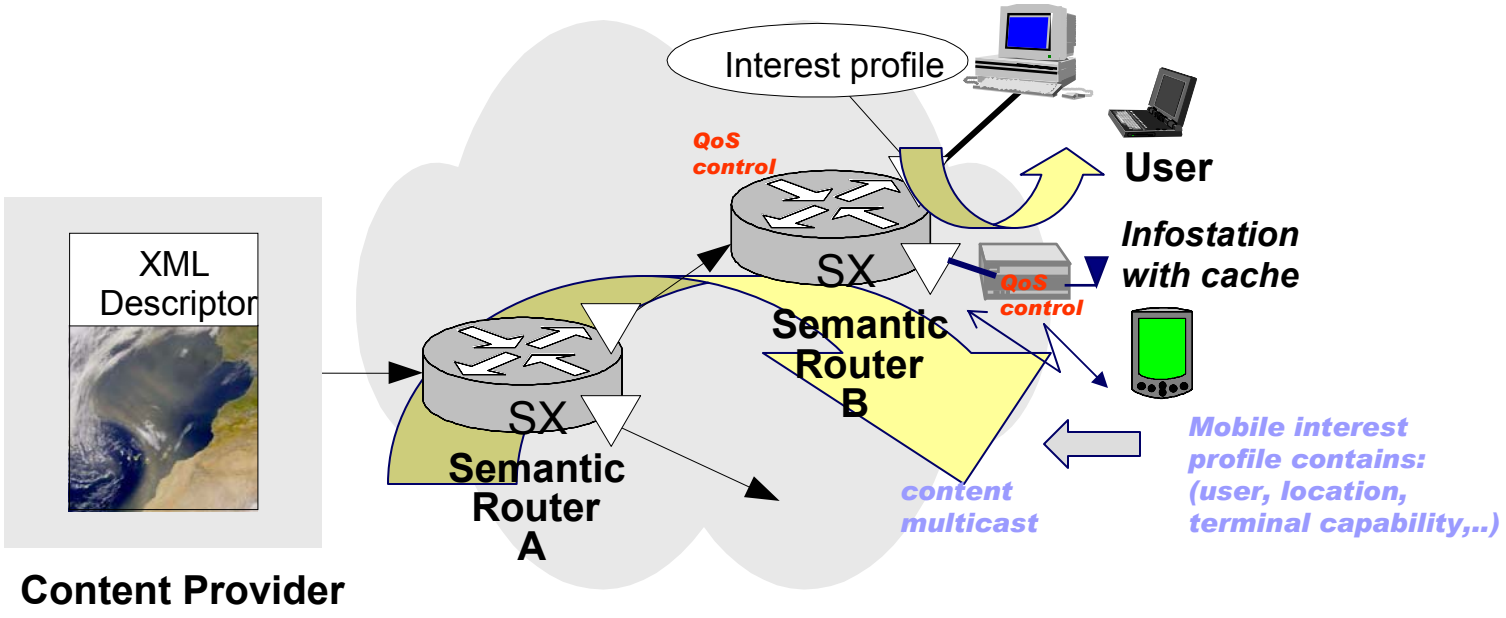
Infostations: MAC Protocol for Pass-Through Mode

- Mobile user passes through Infostation in sec during which ~MB files are downloaded/uploaded
  - Requires modifications to conventional WLAN MAC, including fast synch, pre-authentication, etc. (... related to interworking discussed before)
  - Motivates 2-tier arch with ~10m service zone (for high-speed data transfer) and ~50m access control zone (for sync, authentication, ...)



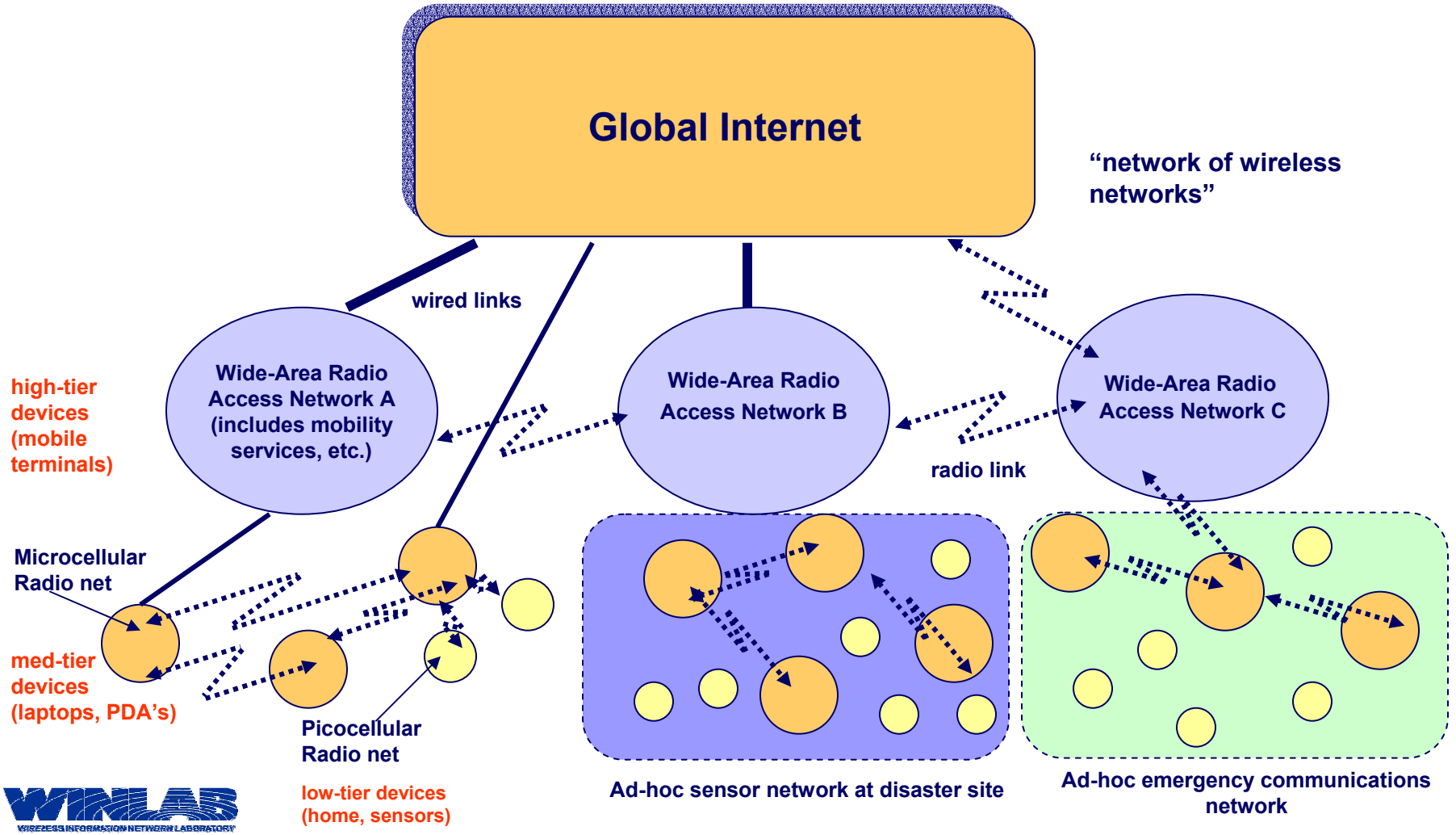
Infostations: Content Delivery

- XML-based content multicasting a possible option for delivering relevant info to mobiles…
  - Mobile users have “information profile” to set up service
  - Useful for building real-time, context- and location-aware services
  - User rofile updated dynamically as location changes and link/terminal capabilities vary
  - QoS may be adjusted for each item of content delivered



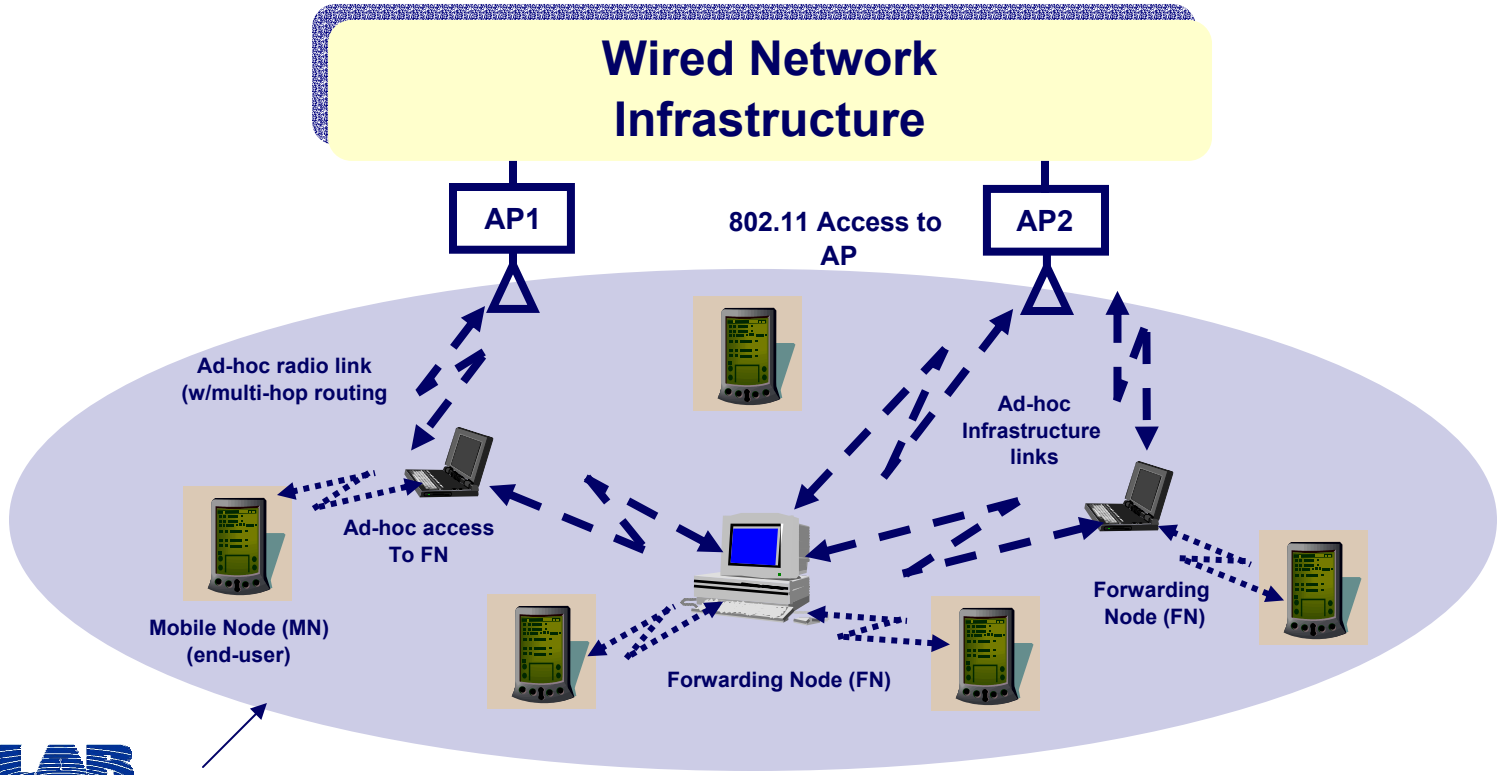
Ad-Hoc Wireless & Sensor Networks

Emerging System Architecture:
"network of wireless networks" concept



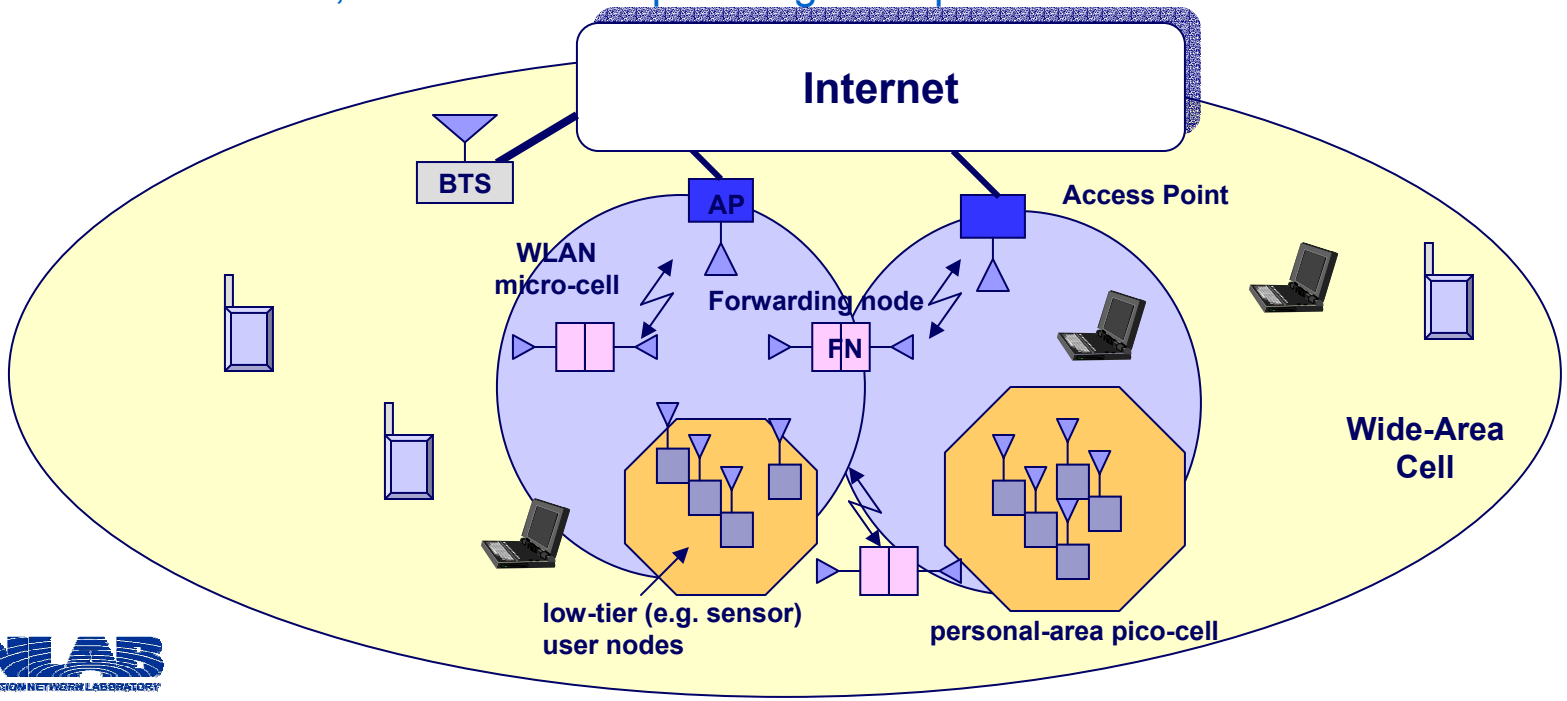
Ad-Hoc Nets: Self-Organizing Extensions to WLAN

- Opportunistic ad-hoc wireless networking concepts starting to mature…
  - Initial use to extend WLAN range in user-deployed networks
  - Based on novel auto-discovery and multi-hop routing protocols
  - extends the utility and reach of low-cost/high speed WiFi equipment

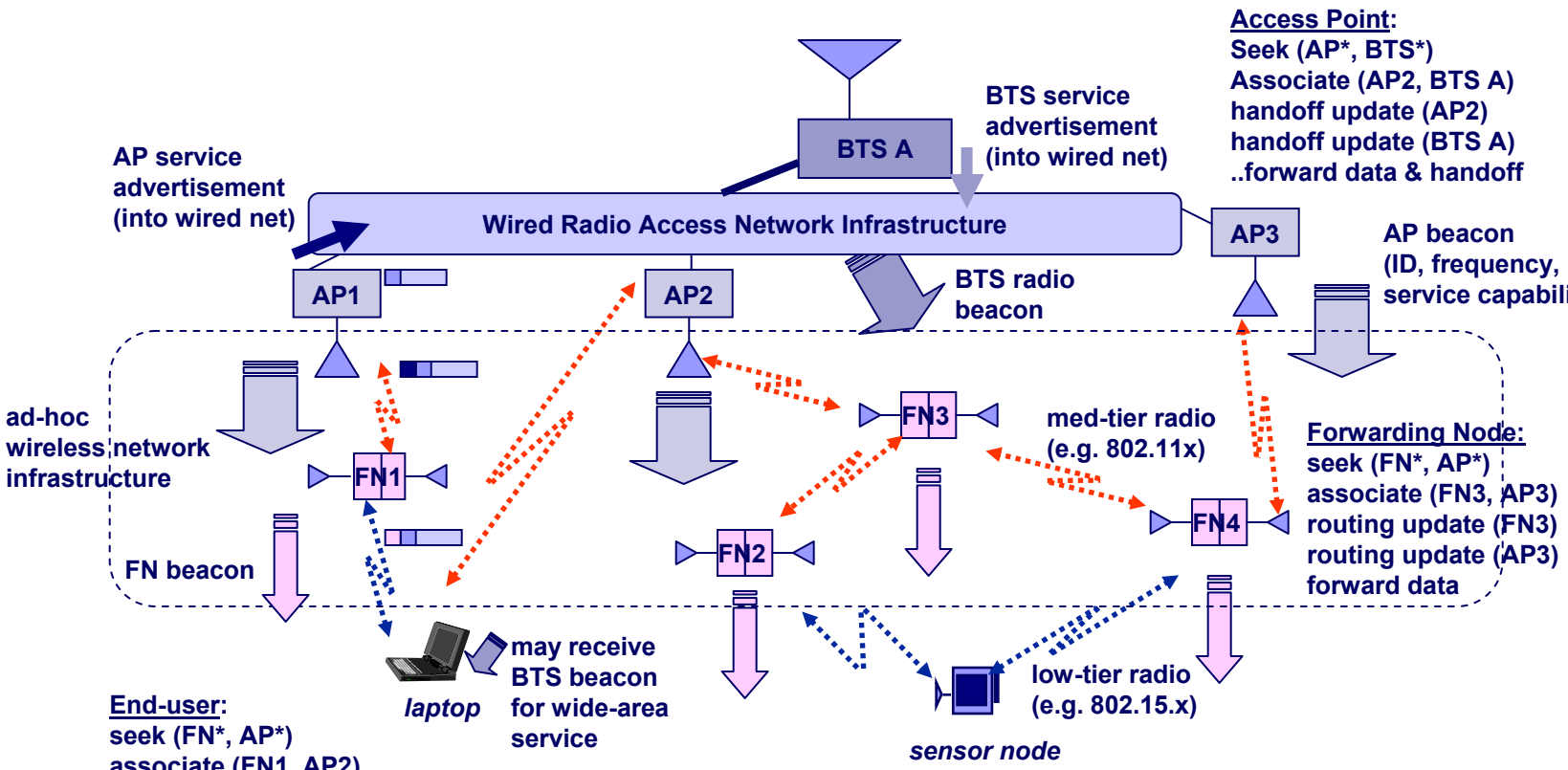


Ad-Hoc Nets: 3-Tier Hierarchy

- Hierarchical, self-organizing ad-hoc network for scalability and integration of low-tier sensor nets, etc. with WLAN & existing Internet services
  - 3 service tiers (cellular, WLAN, personal area/sensors)
  - BS's, AP's, FN's (forwarding radio nodes), user devices
  - automatic discovery and power management protocols
  - hierarchical, ad-hoc multi-hop routing and spatial MAC



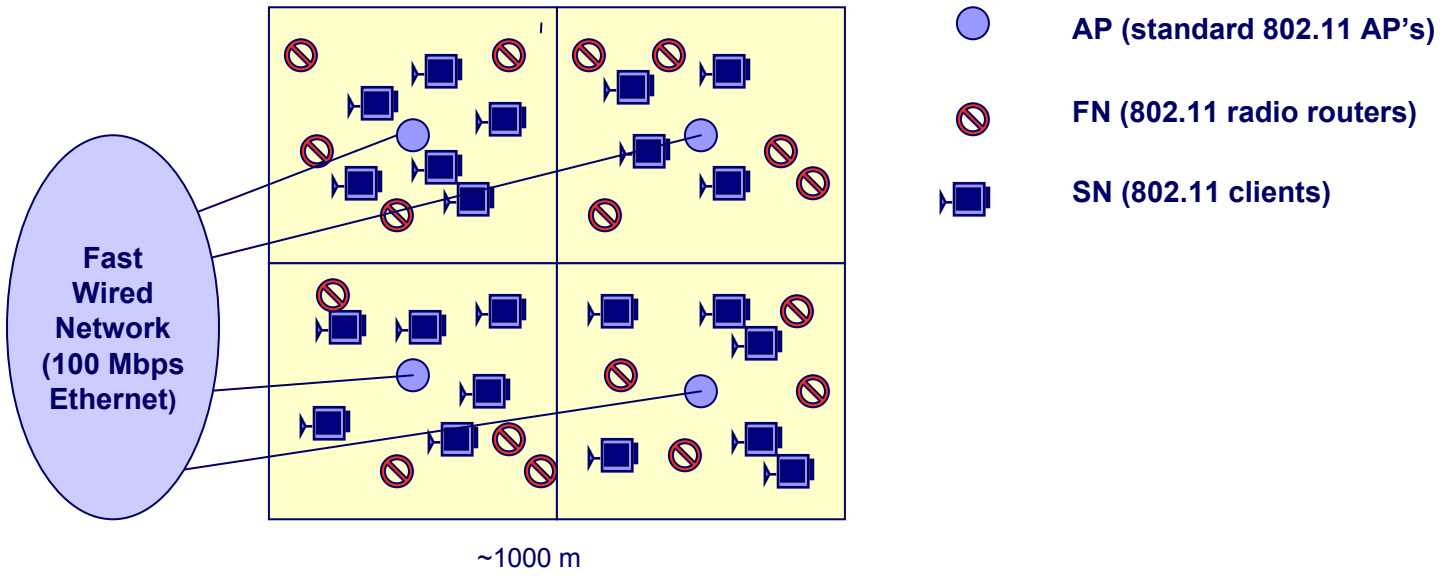
Ad-Hoc Networks:
Discovery and routing protocols



Protocols needed:
Ad-hoc discovery (enhanced beacons, etc.)
Ad-hoc network association
Ad-hoc network routing (extended metrics including energy)
handoff, QoS control, multicast (..features)

Ad-Hoc Networks: Performance of Hierarchical Sensor Network

- ns-2 simulation model developed for capacity evaluation
  - ~1000 sensors in a 1Km**2 rectangular grid with 4 AP's
  - Variable number of FN's and AP's as hierarchical infrastructure
  - Based on 802.11b radio PHY & MAC
  - Different kinds of routing protocols such as DSR & AODV and modifications

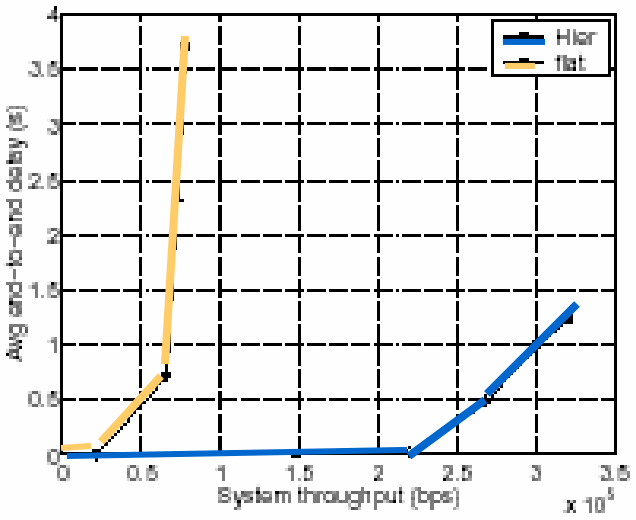


Sensor Network System Model

Ad-Hoc Networks: Performance of Hierarchical Sensor Network

SIMULATION PARAMETERS

Coverage Area	1000*m* X 1000*m*
# of clusters; SN's; FN's; AP's	4; 100; 20; 4
Radio PHY; Radio range	1Mbps; 250m
MAC	Ad-hoc 802.11b
AP-AP link speed	100 Mbps
# of communication pairs	40
# of packets/s generated	1,4,8,12,16,24,32
Packet size	64 bytes
% of SN-Internet traffic	100%



Delay vs. throughput for 40 communication pairs

Sensor Devices

Sensor Devices: Background

- Integrated sensor/actuator + low-power microprocessor + radio
  - *Single chip or compact module*
  - *Wireless networking*
  - *Energy efficient & low cost design*
- Applications of sensors include:
  - *Verticals: factory automation, security, military, logistics, …*
  - *Horizontal market: smart office, home → pervasive computing*
  - *Enables a variety of homeland security related applications: monitoring, disaster recovery, etc.*

MIT DVS

Crossbow Sensor

UC Berkeley MOTE

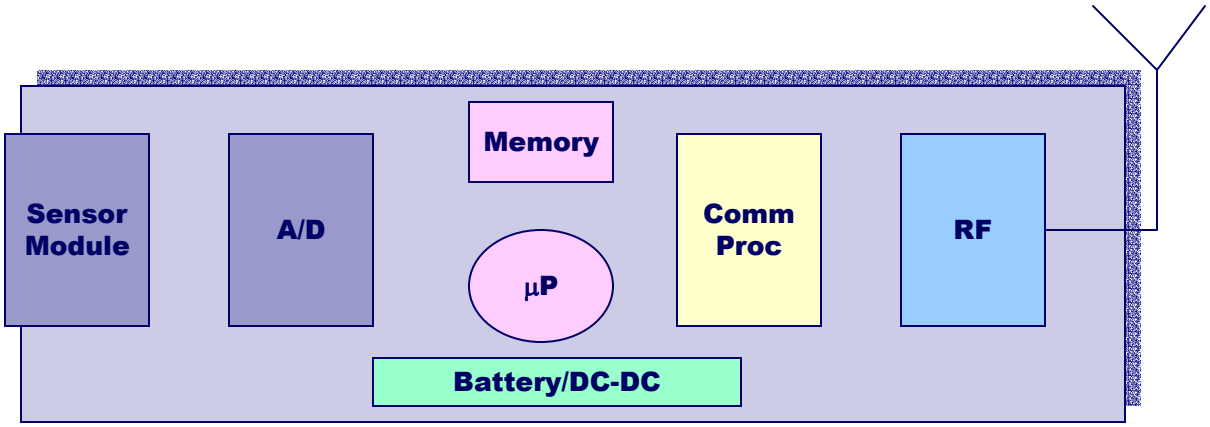
From the engineering perspective, a challenging new "convergence" device:

Integrates computing, communication and sensing
Different design goals: power, size, robustness
Mixed-signal chip or module integration issues, MEMS
New networking paradigms: ad-hoc, self-organizing
Novel software models: data centric, opportunistic, collaborative

Sensor Devices: Hardware Architecture

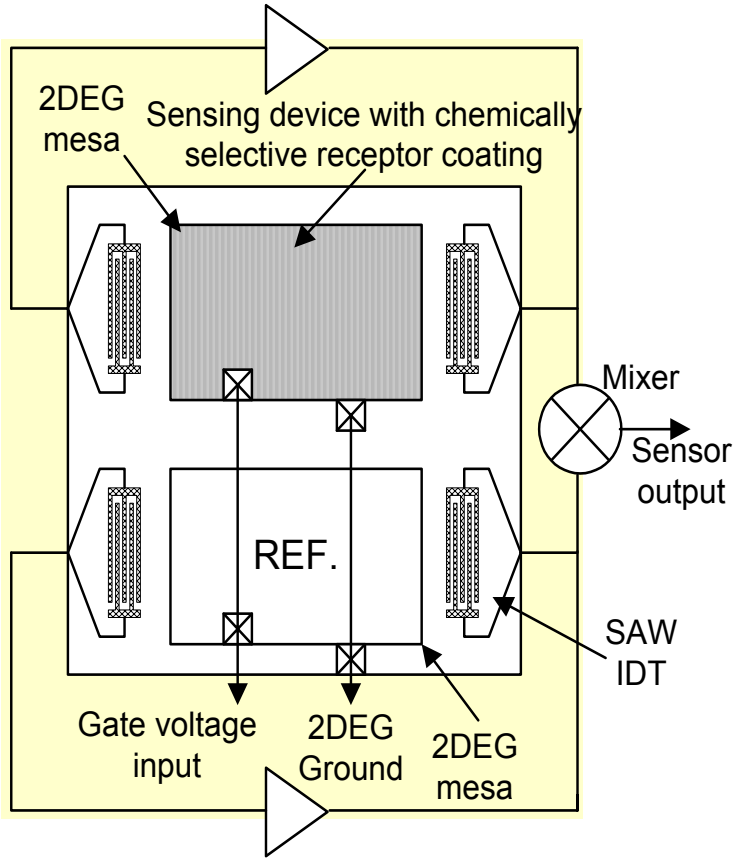
- Sensor architecture considerations:
  - Need for unified system architecture/hardware design to balance functionality vs complexity/power
  - Single chip (SOC) or integrated module (SOP)

Design Issues:
Power consumption
Radio bit-rate
CPU speed
Sensor multimodality
Degree of integration
Standards compatibility
Cost



Sensor Devices: ZnO Materials for multimode operation

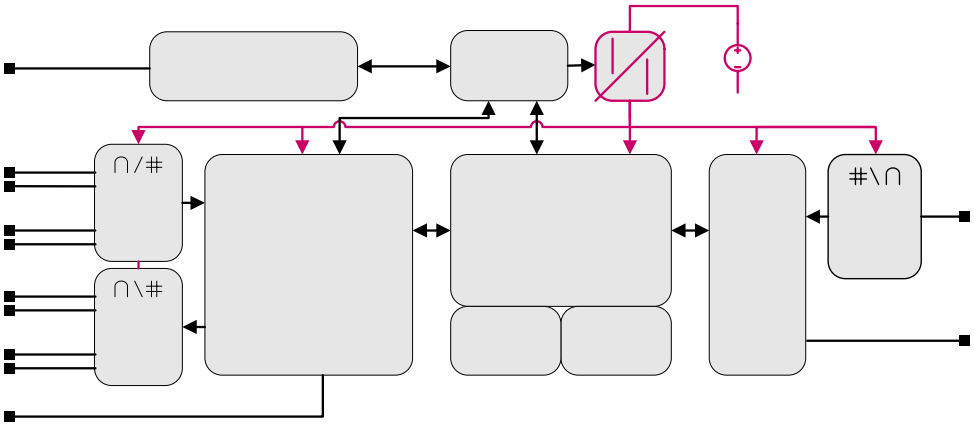
- "Tunable" ZnO sensor developed by Prof. Y. Lu at Rutgers/WINLAB
  - Can be "reset" to increase sensitivity, e.g. in liquids or gas
  - Dual mode (acoustic and UV optic)
  - Applicable to variety of sensing needs



Courtesy of: Prof Y. Lu, Rutgers U

Sensor Devices: Baseband Processor

- Low-power 802.11b + multimodal ZnO sensor under development at WINLAB….
  - Subset of 802.11b functionality for energy conservation
  - ARM RISC core
  - RF “wake-up” module, sensor interface, ..



Experimental Prototypes at WINLAB

Infostations Prototype: System for Rapid Deployment Applications

- **Outdoor Infostations with radio backhaul**
  - for first responders to set up wireless communications infrastructure at a disaster site
  - provides WLAN services and access to cached data
  - wireless backhaul link
  - includes data cache

- **Project includes development of:**
  - high-speed short-range radios
  - 802.11 MAC enhancements
  - content caching algorithm & software
  - hardware integration including solar panels, antennas and embedded computing device with WLAN card

WINLAB's Outdoor Infostations Prototype (2002)

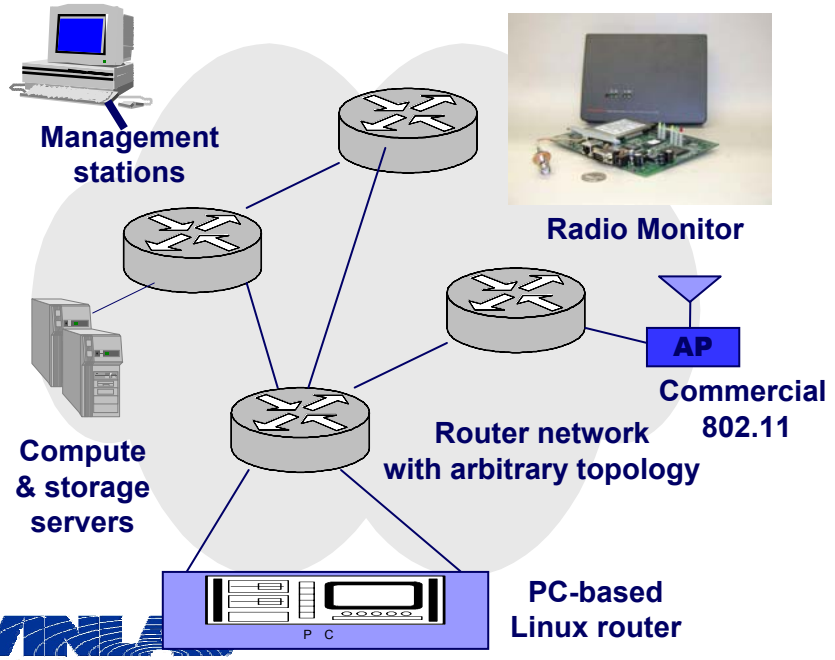
Infostations Prototype: "i-media system"

- **WINLAB's "i-media" prototype for media delivery over wireless networks**
  - 802.11 WLAN AP with MAC optimizations
  - wired network interface (Ethernet, DSL,..)
  - on board processing & cache storage
  - XML-based content routing for information delivery services
- **Project now moving to lab trials stage:**
  - media service demonstrations with wireless service operators
  - military applications....

WINLAB's 'i-media' Infostations prototype 9/03

Ad-Hoc Wireless Network: WINLAB Prototype

- A flexible, open-architecture ad-hoc WLAN and sensor network testbed has been developed...
  - open-source Linux routers, AP's and terminals (commercial hardware)
  - Linux and embedded OS forwarding and sensor nodes (custom)
  - radio link and global network monitoring/visualization tools
  - prototype ad-hoc discovery and routing protocols




Forwarding Node/AP (custom)

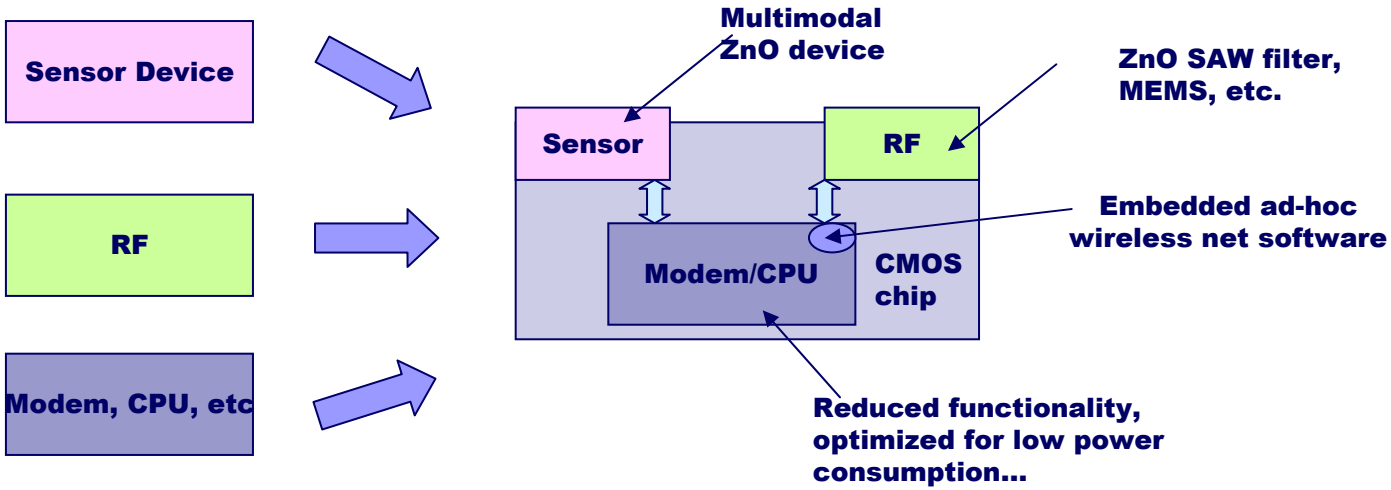
802.11b PDA

802.11b Linux PC


Sensor Node (custom)

Ad-Hoc Net and Sensors: MUSE Sensor Prototype

- "Multimodal" wireless sensor hardware being developed with NJCST funding...
  - novel ZnO materials for tunable sensors
  - integration with low-power wireless transceiver designs
  - focus on an integrated system-on-package or system-on-chip
  - integrated ad-hoc networking software (as outlined earlier)
  - sensor applications, including medical heart monitors, etc.



2002-04 target: Multi-chip module for sub-802.11b
Early medical applications at UMDNJ

2005-06 target: Single chip prototype
Pre-commercial applications w/ partners